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16. ABSTRACT

The objective of this research project was to develop tables of allowable height of cover for various sizes of prefabricated corrugated steel pipe, pipe arches and field assembled corrugated steel structural plate pipe and pipe arches.

Tests of riveted and bolted pipe seam strengths were made and compared with tests made by others. The seam strengths of spot welded and helically corrugated pipes were assumed to be equal to that of riveted pipe. This has been confirmed by tests made by Ohio State University, Building Research Laboratory, Report EES-236.

Using these seam strengths, tables were computed for various types of pipe and pipe arches showing maximum heights of cover for combinations of pipe diameters with gages of steel used in their fabrication. Ring compression theory was used in the calculations of allowable cover, the heights were checked to assure that allowable deflections were not exceeded, and the tables were limited by the application of flexibility factors.

The tables of maximum cover were compatible with recent experience in California, and were adopted for inclusion in the California Division of Highways Planning Manual.

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HIGHWAY RESEARCH REPORT

ALLOWABLE COVER ON CORRUGATED STEEL PIPE

FINAL REPORT

State of California
Transportation Agency
Department of Public Works
Division of Highways

Design Department
Kenneth M. Fenwick
Principal Investigator

Research Report
HPR-PR-1(6) D-4-5

In cooperation with the U. S. Department of Transportation
Federal Highway Administration, Bureau of Public Roads

February 1969

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This project was performed in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, under Agreement No. D-4-5.

The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Bureau of Public Roads.

The project was conducted with the coordinated efforts of several departments of the California Division of Highways as follows: Materials and Research Department (testing), Bridge Department (structural analysis) and Design Department (review and implementation). Mr. E. F. Nordlin of Materials and Research directed the testing program; Mr. A. E. Bacher and Mr. F. G. Gillenwaters of the Bridge Department made the structural analysis. The Design Department established certain design limitations other than structural and prepared departmental instructions. The study was conducted in coordination with representatives of the corrugated metal pipe industry.

Acknowledgment is made to the California Corrugated Pipe Association for their cooperation and for technical information which was necessary for the completion of this study.

ABSTRACT

The objective of this research project was to develop tables of allowable height of cover for various sizes of prefabricated corrugated steel pipe, pipe arches and field assembled corrugated steel structural plate pipe and pipe arches.

Tests of riveted and bolted pipe seam strengths were made and compared with tests made by others. The seam strengths of spot welded and helically corrugated pipes were assumed to be equal to that of riveted pipe. This has been confirmed by tests made by Ohio State University, Building Research Laboratory, Report EES-236.

Using these seam strengths, tables were computed for various types of pipe and pipe arches showing maximum heights of cover for combinations of pipe diameters with gages of steel used in their fabrication. Ring compression theory was used in the calculations of allowable cover, the heights were checked to assure that allowable deflections were not exceeded, and the tables were limited by the application of flexibility factors.

The tables of maximum cover were compatible with recent experience in California, and were adopted for inclusion in the California Division of Highways Planning Manual.

INTRODUCTION

Prior to 1963 the California Division of Highways based the allowable cover on corrugated metal pipe and structural steel pipes on empirical tables. The expanded highway programs for high speed, high standard roads in mountainous terrain have greatly increased the grading quantities. The consequent increase in fill heights focused attention on the need for a critical reexamination of culvert design. This research project covers the examination of the structural design of corrugated steel pipes. The objective of the study was to determine allowable heights of cover for prefabricated CMP and bolted structural plate pipe.

CONCLUSIONS AND RECOMMENDATIONS

1. The determination of design values for the metal used in the fabrication of corrugated metal pipes and pipe arches and the confirmation of seam strength by testing are primary considerations in determining the allowable cover for any gage-diameter relationship. It is necessary to specify minimum mechanical properties for the metal used in flexible culverts.

2. The use of ring compression theory, when limited by deflection and flexibility factor calculations, will provide a reasonable approximation for determining allowable cover over corrugated metal culverts. Methods adopted as a result of this study can be applied to all flexible steel culverts regardless of diameter, corrugation, configuration or method of fabrication.

3. Previously used empirical tables should be replaced by revised tables based on recommended values of allowable cover detailed in this report.

4. It should be noted that this report is concerned with structural adequacy only. No allowances were made or factors provided for determining heavier gages that would be required by corrosive or abrasive site conditions.

PROJECT ANALYSIS AND PROCEDURES

I General

The computation of allowable heights of cover was based on determination of seam strengths, application of ring compression theory, checking for allowable deflection, and limiting the tables to size and gage combinations that met criteria for handling and installation rigidity as defined by the flexibility factor.

Because of variables in pipe manufacture, loading stresses caused by various placement procedures, and varying site conditions, a safety factor of four was used in the ring compression calculations. A safety factor of four also was used in the deflection calculations and there is sound basis for this value. Flexible conduits fail by excessive deformation and reach that state at a deflection of approximately 20% of the initial diameter. A maximum limiting deflection of 5% is recommended by Spangler and the American Iron and Steel Institute which is one-fourth the allowable deflection.

For the scope of this study, the phrase "metal pipe" refers to steel pipes only.

For dead load, a weight of earth of 100 pounds per cubic foot was used for comparison with data submitted by the California Corrugated Metal Pipe Association although AASHO allows 84 pounds per cubic foot. The American Iron and Steel Institute handbook uses 100 pounds per cubic foot for computing dead load.

Live loads were not used in the computations as they would be negligible when considering maximum heights of cover.

II Seam Strength

California Division of Highways Standard Specifications allow fabrication of corrugated metal pipe with riveting, resistance spot welding, helical continuous lock seams or helical continuous welded seams. The riveted seam was the original method of manufacture, and all subsequent methods of fabrication have been required to meet riveted seam strengths as the controlling value. The computation of the cover height tables was based on riveted seam strength with corrugations normal to the pipe axis.

Tables 1, 2 and 3 give the pertinent seam strength data that were available from the sources listed in the column headings. In each Table, the value in the column marked with an asterisk were used in the computation of the allowable height of cover in Tables 4 to 9 inclusive.

TABLE 1

ULTIMATE SEAM STRENGTH
2-2/3" x 1/2" Corrugations
Kips per foot of seam - average values

Gage	Rivets	Division M. & R. Tests	* Calif. C.M.P. Assoc.	Pittsburgh Testing Lab.	Armco Handbook
16	5/16" Single	11.0	12.4	16.9	8.0
14	5/16" Single		16.5		
12	3/8" Single		24.6		
10	3/8" Single	20.1	30.6	30.2	30.0
8	3/8" Single		37.0x		
16	5/16" Double	24.0	27.8	34.1	18.0
14	5/16" Double		30.2		
12	3/8" Double		49.9		
10	3/8" Double	43.6	53.0	64.0	56.0
8	3/8" Double		56.0x		

* These values used in computing the tables.

x No valid test results available. Figures shown were extrapolated.

TABLE 2

ULTIMATE SEAM STRENGTH
3" x 1" Corrugations
Kips per foot of seam - average values

Gage	Rivets	Hales Testing Lab.	Calif. C.M.P. Assoc.	Pittsburgh Testing Lab. (8½" bolts)	* Townsend's Theoret. Values
16	3/8" Double	27.5	28.0	32.0	25.8
14	3/8" Double			36.8	34.3
12	7/16" Double			63.6	53.0
10	7/16" Double			92.6	61.0
8	7/16" Double			116.7	64.0

*These values used in computing the tables.

TABLE 3

ULTIMATE SEAM STRENGTH
6" x 2" Corrugations
Kips per foot of seam - average values

Gage	Bolts	Pittsburgh Testing Lab.	* Armco Handbook	Calif. C.M.P. Assoc.
12	4-bolt	47.3	42.0	43.0
10	4-bolt		62.0	
8	4-bolt	90.4	81.0	81.0
7	4-bolt		93.0	
5	4-bolt		112.0	
3	4-bolt	140.2	132.0	132.0
1	4-bolt		144.0	
1	6-bolt		184.0	

* These values used in computing the tables.

From supplemental data available, it appeared that part of the variation in seam strengths reported was due to variation in strength of the base metal. To make maximum height of cover tables valid, it is necessary to specify minimum strengths for the steel used in fabrication.

Materials are required to conform to AASHO Designation: M36 for corrugated metal pipe and AASHO Designation: M167 for structural plate pipe. Under these specifications, steels as weak as 40,000 psi ultimate tensile strength could be furnished. To supplement these requirements the California Standard Specifications specify the following mechanical requirements:

	CMP	SSP
Tensile Strength, psi	45,000 min.	42,000 min.
Yield Point, psi	33,000 min.	28,000 min.
Elongation in 2 inches, percent	20 min.	30 min.

These requirements apply to flat sheets prior to corrugation.

The seam strengths chosen for the calculation of maximum heights of cover in Tables 4 to 9 are consistent with the above specifications.

III. Soil Support

The support strength of the soil should be established. This has been the indeterminate factor in design. The level of support capacity is determined by soil structure and compaction. Soils which are granular and easily compacted have excellent support strength levels. Soils which are heavy in clay or silt content are low in support strength and difficult to compact. Significant movement under load may be anticipated for these poor structural soils. Design must be based upon presumed levels of compaction. The State of California specifies 95% compaction of the backfill material surrounding the culvert. The exact level of support resistance, a combination of support strength of soil and degree of compaction, can only be approximated. Because of this limitation each theory can only be an approximation. Unfortunately, the problem of approximation is compounded, as a small change in external pressure distribution produces large changes in analytical results.

This inability to predict definite values of soil support emphasizes the necessity for using a large safety factor in computing maximum heights of cover.

IV Ring Compression Computations

The theory of the metal conduit as a compression ring was developed by H. L. White and J. P. Layer and appeared under the title, "The Corrugated Metal Conduit As A Compression Ring" in Highway Research Board Proceedings, 1960.

This approach presumes good compacted soil developing a uniform pressure around the periphery of the culvert, and assumes the soil to be inelastic so that any shape will be rigidly maintained. With this assumption of soil behavior, it can be shown that the culvert will act as a ring in compression. The value of this approach is only as good as the assumption of uniform radial pressure from the soil. With 95% minimum relative compaction specified and a safety factor used in the calculations, it is considered valid for the first step computations of maximum heights of cover.

For ring compression, the load is based on the weight of the soil acting vertically and uniformly across a plane at the top of the culvert.

Thus $P = H \times w$

where P = Unit load, $lb/ft.^2$
H = Height of cover, feet
w = Density of soil, $lb/ft.^3$
= 100 pcf for calculation of tables

Ring compression is:

$$C = \frac{P \times S \times SF}{2}$$

where C = Seam strength, lb/ft.
S = Span or diameter, feet
SF = Safety factor
= 4 for calculation of tables

Combining and solving for H

$$H = \frac{2C}{w \times S \times SF}$$

Example: A structural plate pipe 18 feet in diameter, 10 gage, seam strength 62,000 pounds per foot from Table 3, weight of soil 100 pounds per cubic foot and safety factor of 4.

$$H = \frac{2 \times 62{,}000}{100 \times 18 \times 4}$$

$$= 17.2 \text{ say } 18 \text{ feet}$$

V. Deflection Calculations

Another design approach is the deflection analysis by Spangler which was published under the title, "Analysis of Loads and Supporting Strengths, and Principles of Design for Highway Culverts," Prof. M. G. Spangler, in Highway Research Board proceedings, 1946. He used loadings described in "The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments," Anson Marston, Iowa State College Bulletin 96, 1930.

Spangler's method considers uniform pressure across the plane at the top of the culvert, uniform pressure resistance across the plane at the invert, and horizontal side pressures as a function of lateral displacement. When these loads are applied to the ring and solved for deflection, the equation is:

$$d = \frac{D_1 \ K \ W_c \ r^3}{EI + 0.061 \ E' \ r^3}$$

where d = Deflection of the culvert under load, in.
D_1 = Deflection lag factor
K = Bedding constant
W_c = Load on the culvert, lb/lin. in
r = Radius of the culvert, in.
E = Modulus of elasticity of the metal, lb/in.^{2}
I = Moment of inertia of the culvert wall, in^4/in.
E'= Horizontal soil modulus, lb/in.^{2}

As previously stated, deflection under load was limited to 5% of the initial diameter of the culvert.

The load W_c in the above formula was determined by Marston's equation:

$$W_c = \frac{C_c \ w \ B^2}{12}$$

C_c = Factor based on $\frac{H}{B_c}$ and

obtained from a chart of Marston's equations

w = Density of soil, lb/ft.^{3}
B_c= Span of culvert, feet
H = Height of cover, feet

Example: Using the same example of a structural plate pipe 18 feet in diameter and weight of soil 100 pounds per cubic foot.

$\frac{H}{B_c}$ = 1.0 and C_c = 0.9 from chart of Marston's equations, based on a settlement ratio of - 0.3, positive projection conduit.

$$W_c = \frac{C_c \ w \ B^2}{12}$$

$$= \frac{0.9 \times 100 \times 18^2}{12}$$

= 2430 lb/lin. in.

Using D_1 = 1.25, K = 0.10, E = 30 x 10^6 lb/in.^{2}, I = 0.0782 in^4/in. and E' = 700 lb/in.^{2}

$$d = \frac{D_1 K W_c r^3}{EI + 0.061 E'r^3}$$

$$= \frac{1.25 \times 0.10 \times 2430 \times (9 \times 12)^3}{30 \times 10^6 \times 0.0782 + 0.061 \times 700 \times (9 \times 12)^3}$$

$$= 6.9 \text{ in.}$$

Since the allowable deflection is 5% of the initial diameter, d = 0.05 x 216 = 10.8 in. and the computed deflection is within safe limits.

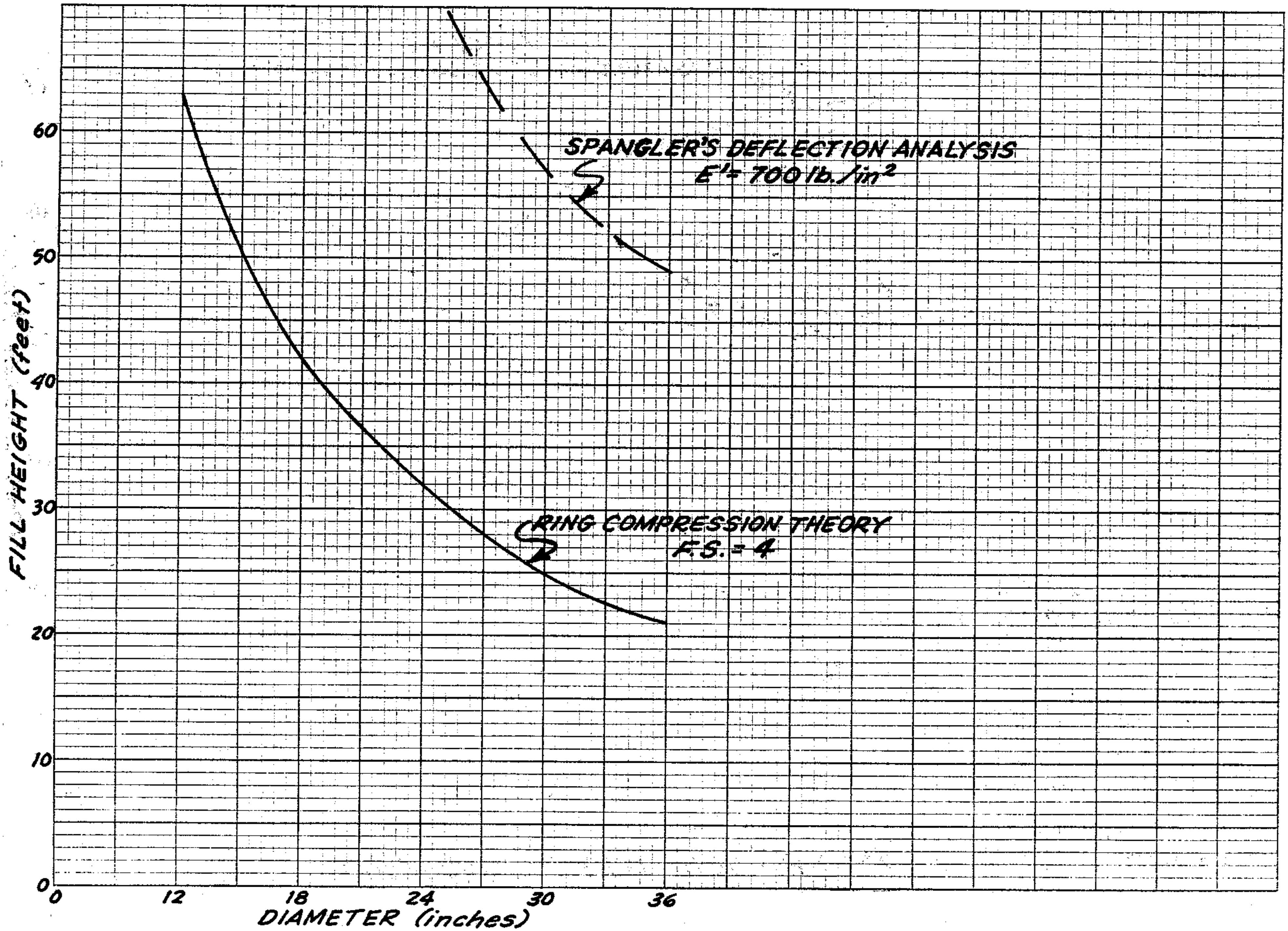
Charts 1 through 4 show comparisons of allowable fill heights determined by ring compression theory versus Spangler's deflection analysis.

It can be seen that ring compression values are more conservative than Spangler's values when the horizontal soil modulus (E') is 1400 lb/in.^{2}, and in most cases when E' = 700 lb/in.^{2}

Since the value 1400 lb/in.^{2} approximates backfill with 95% relative compaction and 700 lb/in.^{2} represents 85% compaction, it is apparent that the ring compression values are conservative in all cases.

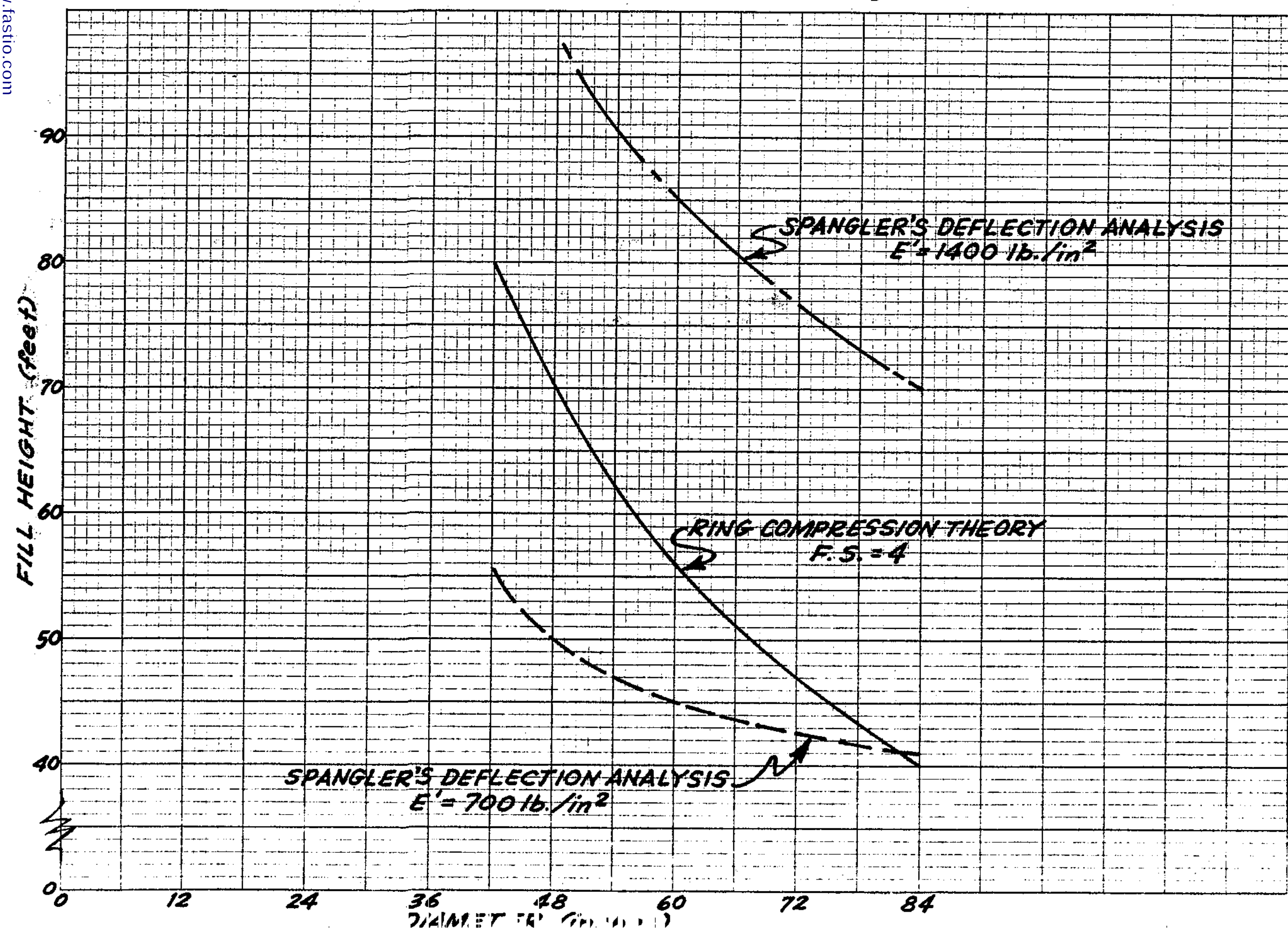
CORRUGATED METAL PIPE - 16 Gage

CHART 1



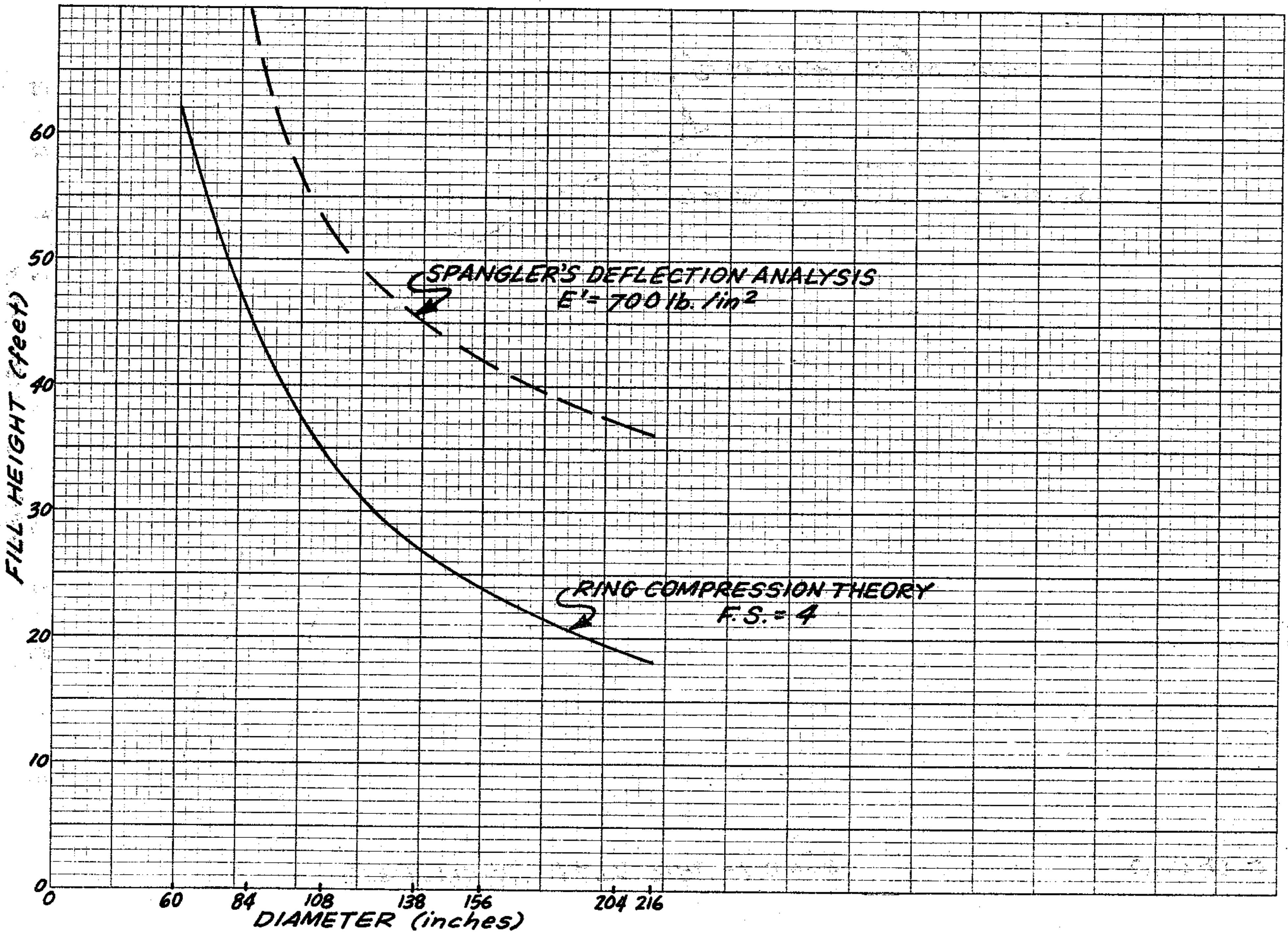
CORRUGATED METAL PIPE - 8 Gage

CHART 2



STRUCTURAL PLATE PIPE - 10 Gage

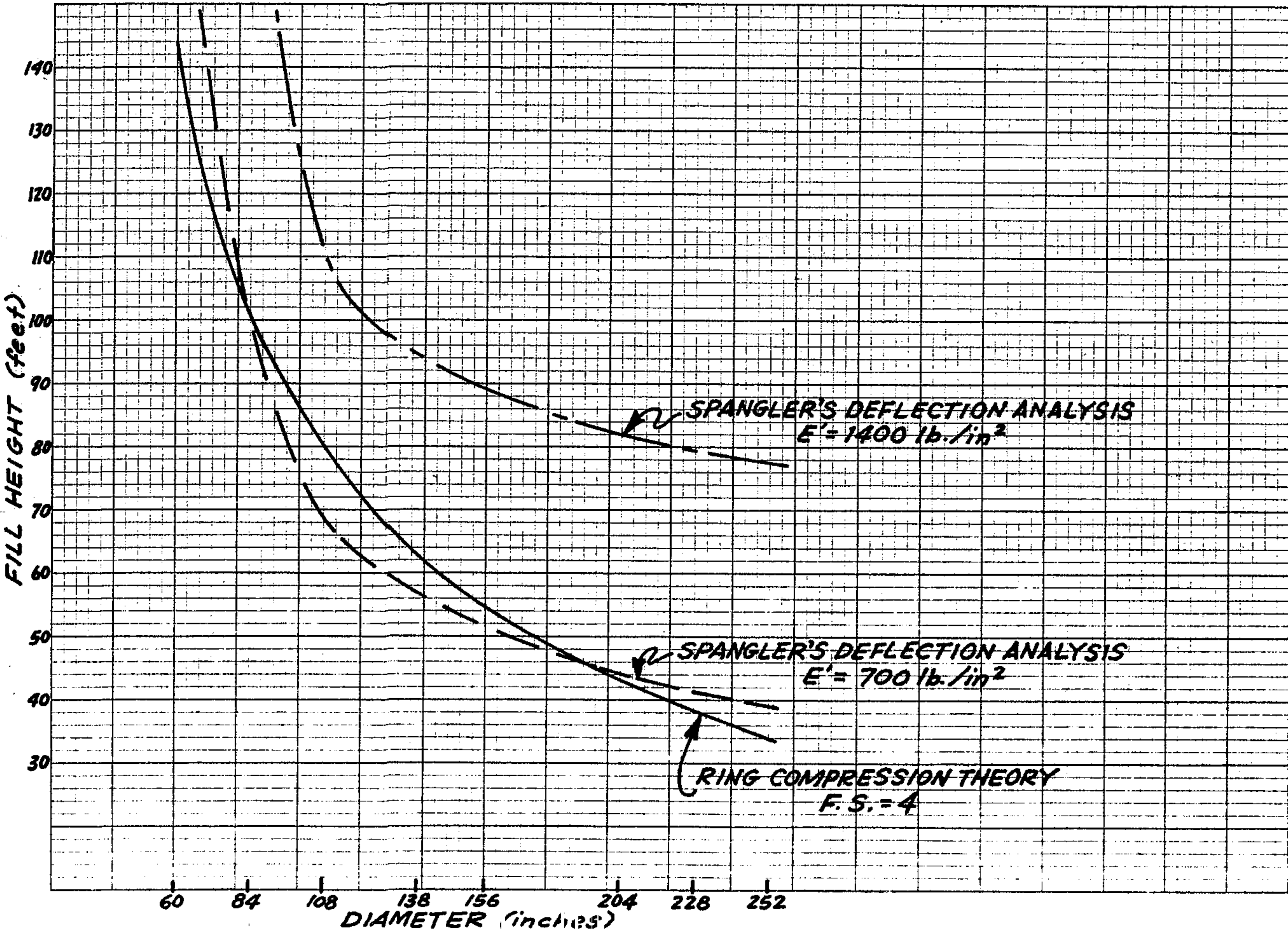
CHART 3



K+E 5 X 5 TO 1/2 INCH 46 0862
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

STRUCTURAL PLATE PIPE - 1 Gage

CHART 4



VI Flexibility Factor Computations

Flexibility factors are indicators of rigidity of flexible conduits, and they are used to determine if various diameter and gage combinations will maintain their shape satisfactorily during transporting, handling and installation. The flexibility factor is directly proportional to the square of the diameter and inversely proportional to the product of the modulus of elasticity of the metal and the moment of inertia of the cross section of the pipe wall.

The formula is expressed as follows:

$$FF = \frac{D^2}{EI}$$

Where FF = Flexibility Factor
D = Diameter of pipe, in.
E = Modulus of elasticity, lb/in.^{2}
I = Moment of inertia, in^4/in.

Maximum values of these factors have been established by the industry based on experience. The maximum flexibility factors used were as follows:

For 2=2/3" x 1/2" corrugation	FF	= 0.0433
3" x 1" corrugation		= 0.0333
6" x 2" corrugation		= 0.0200

The factor 0.0333 for 3 " x 1" corrugations was established by interpolating between the flexibility factors for 2-2/3" x 1/2" corrugations and 6" x 2" corrugations. The moments of inertia of the various corrugation patterns were used as the basis of interpolation.

Flexibility factors were computed to determine the largest pipe diameter allowed for each diameter and gage relationship. In the computations for pipe arches, the span was used in computing the flexibility factors. The attached tables were limited in scope by the application of these factors:

Example: Same structural plate pipe 18 feet in diameter, 10 gage, E = 30,000,000 lb/in.^{2}, I = 0.0782 in^4/in. from AISI Handbook.

$$FF = \frac{(18 \times 12)^2}{30 \times 10^6 \times 0.0782} = 0.0199$$

The 18-foot diameter, 10 gage combination was included in Table 8 as it does not exceed the 0.0200 maximum allowable value.

VII Tables of Maximum Height of Cover

Tables 4 through 9 tabulate the results of this investigation showing maximum height of cover allowable for various corrugated metal pipes, pipe arches, structural plate pipes and structural plate pipe arches.

The use of these tables is contingent on the use of conduits that meet the specifications discussed under II Seam Strength. It presupposes that the backfill will have a minimum relative compaction of 95% as required by the Standard Specifications of the California Division of Highways. Shaped bedding is required by Standard Plans for pipes 42 inches in diameter and less than 72 inches in diameter with 50 feet or more depth of cover, and for all pipes 72 inches in diameter and over with any depth of cover.

No allowance was made for corrosive or abrasive site conditions. When heavier gage metal is specified to counteract these conditions, no increase in height of cover should be allowed.

The columns in the tables noted "Present Design Planning Manual" give values of maximum allowable height of cover that are compatible with recent experience in California, and as noted, were adopted for use by the Division of Highways.

TABLE 4

Maximum Height of Cover for Circular Steel Pipe
With 2-2/3" x 1/2" Corrugations

Dia. Inches	Maximum height of cover (feet)														
	5/16" Rivets						3/8" Rivets								
	16 gage			14 gage			12 gage			10 gage			8 gage		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	SINGLE RIVETED														
12	60	82	63	100	109	83									
15	50	65	50	70	88	66	100								
18	40	55	42	60	73	55	100	109	84						
21	35	46	36	50	62	47	80	93	72						
24		41	32	45	54	42	70	82	61	100	102	75			
30		33	25	30	44	33	45	65	49	70	81	60	100	81	74
36		28	21		36	28	30	54	41	45	68	50	100	68	62
	DOUBLE RIVETED														
42		53	40		57	43	25	94	72	35	100	76	100	100	80
48		46	35		50	38	25	82	63	35	88	67	100	88	70
54		41			44	34	20	73	56	35	78	59	80	78	63
60		37			40			66	50	25	70	53	40	70	56
66		34			37			61	46	20	65	49	30	65	51
72		32			34			55		15	58	45	30	58	47
84		26			29			47			50	40	20	50	40

Col. "A" - Old Design Planning Manual (Empirical)

Col. "B" - Calif. CMP Ass'n. (Safety Factor = 3)

Col. "C" - Present Design Planning Manual (Safety Factor = 4)

TABLE 5

Maximum Height of Cover for Circular Steel Pipe With 3" x 1" Corrugations

Dia. Inches	Maximum height of cover (feet)									
	Double 3/8" rivets				Double 7/16" rivets					
	16 gage		14 gage		12 gage		10 gage		8 gage	
	A	B	A	B	A	B	A	B	A	B
36		43		57		88				
42		37		49		76		87		92
48		32		43		66		76		80
54	32	29	35	38	58	59	62	68	62	71
60	29	26	31	34	52	53	55	61	55	64
66	26	23	28	31	47	48	50	56	50	58
72	24	22	26	29	43	44	46	51	46	53
78	22		24	26	40	41	42	47	42	49
84	20		22	25	37	38	40	43	40	46
90	19		21	23	35	35	37	41	37	43
96	18		19		32	33	35	38	35	40
102	17		18		30	31	32	36	32	38
108			17		29	29	31	34	31	36
114			16		27	28	29	32	29	34
120					26	26	27	30	27	32

Col. "A" - Calif. CMP Ass'n. (Safety Factor = 4)

Col. "B" - Present Design Planning Manual (Safety Factor = 4)

TABLE 6

Maximum Height of Cover for Steel Pipe-Arches
With 2-2/3" x 1/2" Corrugations

Span-rise inches	Corner radius inches	Maximum height of cover (feet)			
		5/16" rivets		3/8" rivets	
		16 gage	14 gage	12 gage	10 gage
	SINGLE RIVETED				
18 x 11	$3\frac{1}{2}$	12			
22 x 13	4	11			
25 x 16	4	10			
29 x 18	$4\frac{1}{2}$	9	9		
36 x 22	5	8	8		
43 x 27	$5\frac{1}{2}$	8	8		
	DOUBLE RIVETED				
50 x 31	6	7	7	7	
58 x 36	7	7	7	7	7
65 x 40	8			7	7
72 x 44	9			7	7

Cover limited by corner soil pressures of $1\frac{1}{2}$ tons per square foot.

Present Design Planning Manual (Safety Factor = 4)

TABLE 7

Maximum Height of Cover for Steel Pipe-Arches
With 3" x 1" Corrugations

Span-rise inches	Corner radius inches	Maximum height of cover (feet)				
		Double 3/8" rivets		Double 7/16" rivets		
		16 gage	14 gage	12 gage	10 gage	8 gage
43 x 27	7-3/4	11	11			
65 x 40	12	11	11	11	11	
72 x 46	14	12	12	12	12	
73 x 55	18	15	15	15	15	
81 x 59	18		13	13	13	13
103 x 71	18			10	10	10
128 x 83	18				8	8

Cover limited by corner soil pressures of $1\frac{1}{2}$ tons per square foot

Present Design Planning Manual (Safety Factor = 4)

TABLE 8

Maximum Height of Cover for Structural Steel Plate Circular Pipe With 6" x 2" Corrugations

Dia. Inches	Maximum height of cover (feet)																							
	4-bolt seams																					6-bolt seams		
	12 gage			10 gage			8 gage			7 gage			5 gage			3 gage			1 gage			1 gage		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
60	50	56	42	60	82	62	70	108	80	80	124	93	100	149			176			192				
66	40	52	39	50	75	57	60	98	73	70	112	85	80	135	102	100	160			174				
72	40	47	35	50	68	52	60	90	67	70	103	78	80	124	94	90	146		100	160				
78	35	44	33	45	63	48	55	83	62	60	95	72	70	115	87	80	135		90	147				
84	35	40	30	45	59	45	55	77	57	60	88	67	70	106	80	80	125	95	90	137				
90	25	38	28	40	55	42	45	72	54	55	82	62	60	99	75	70	117	88	80	128	96			
96	25	35	27	40	51	39	45	67	50	55	77	58	60	93	70	70	110	83	80	120	90			
102	15	33	25	35	48	37	40	63	47	45	73	55	55	87	66	60	103	78	70	113	85			
108	15	31	24	35	45	35	40	60	45	45	68	51	55	83	63	60	97	74	70	106	80			
114	10	30	22	30	43	33	35	56	42	40	65	49	50	78	59	55	92	70	60	101	76			98
120	10	28	21	30	41	31	35	54	40	40	62	47	50	74	56	55	88	66	60	96	72			92
126		27	20	25	39	30	35	51	38	40	59	45	45	71	54	50	84	63	60	91	69			88
132		26	19	25	37	28	35	49	37	40	56	43	45	68	51	50	80	60	60	87	66			84
138		25	18	20	35	27	30	47	35	35	53	41	40	65	49	45	76	58	55	83	63			80
144		23	18	20	34	26	30	45	34	35	51	39	40	62	47	45	73	55	55	80	60			77
150		22	17	15	33	25	30	43	32	35	48	38	35	59	45	40	70	53	50	77	58			74
156		22	16	15	31	24	30	41	31	35	47	36	35	57	44	40	67	51	50	73	56			71
162		21	16	15	30	23	25	40	30	30	46	35	35	55	42	40	65	49	45	71	54			68
168		20	15	15	29	22	25	38	29	30	44	34	35	53	40	40	63	47	45	68	52			66
174		19	15	10	28	22	25	37	28	30	42	32	30	51	39	35	60	46	40	66	50			64
180		19	14	10	27	21	25	36	27	30	41	31	30	49	38	35	58	44	40	64	48			62
186		18	14		26	20		34	26		40	30		48	36		56	43		62	47			60
192		17			25	20		33	25		38	29		46	35		55	42		60	45			58
198		17			25	19		32	25		37	29		45	34		53	40		58	44			56
204		16			24	19		31	24		36	28		44	33		51	39		56	43			54
210		16			23	18		30	23		35	27		42	32		50	38		55	42			53
216		15			23	18		30	23		34	26		41	31		49	37		53	40			51
222		15			22			29	22		33	26		40	31		47	36		52	39			50
228		15			21			28	21		32	25		39	30		46	35		50	38			49
234		14			21			27	21		31	24		38	29		45	34		49	37			47
240		14			20			27			31	24		37	28		44	33		48	36			46
246		14			20			26			30	23		36	28		43	33		46	35			45
252		13			19			25			29	22		35	27		41	32		45	34			44

Col. "A" - Old Design Planning Manual (Empirical)
Col. "B" - Calif. CMP Ass'n. (Safety Factor = 3)
Col. "C" - Present Design Planning Manual (Safety Factor - 4)

TABLE 9

Maximum Height of Cover for Structural Steel Plate Pipe-Arches With 6" x 2" Corrugations

Span	Rise	Maximum height of cover - (feet)							
		Corner soil bearing 1½ tons per square foot				Corner soil bearing 3 tons per square foot			
		12 gage	10 gage	8 gage	7 gage	12 gage	10 gage	8 gage	7 gage
		18" CORNER RADIUS							
6'- 1"	4'- 7"	15				30			
7'- 0"	5'- 1"	13				26			
7'-11"	5'- 7"	12				24			
8'-10"	6'- 1"	10				20			
9'- 9"	6'- 7"	9				18			
10'-11"	7'- 1"	8				16			
12'-10"	8'- 4"	8				16			
14'- 1"	8'- 9"	8				16			
15'- 4"	9'- 3"	8				16			
15'-10"	9'-10"	7				14			
16'- 7"	10'- 1"	7				14			
		31" CORNER RADIUS							
13'- 3"	9'- 4"	11					22		
14'- 2"	9'-10"	11					22		
15'- 4"	10'- 4"	10					20		
16'- 3"	10'-10"		9				18		
17'- 2"	11'- 4"		9				18		
18'- 1"	11'-10"			8				16	
19'- 3"	12'- 4"			8				16	
19'-11"	12'-10"			7				14	
20'- 7"	13'- 2"				7				14

Present Design Planning Manual (Safety Factor = 4)